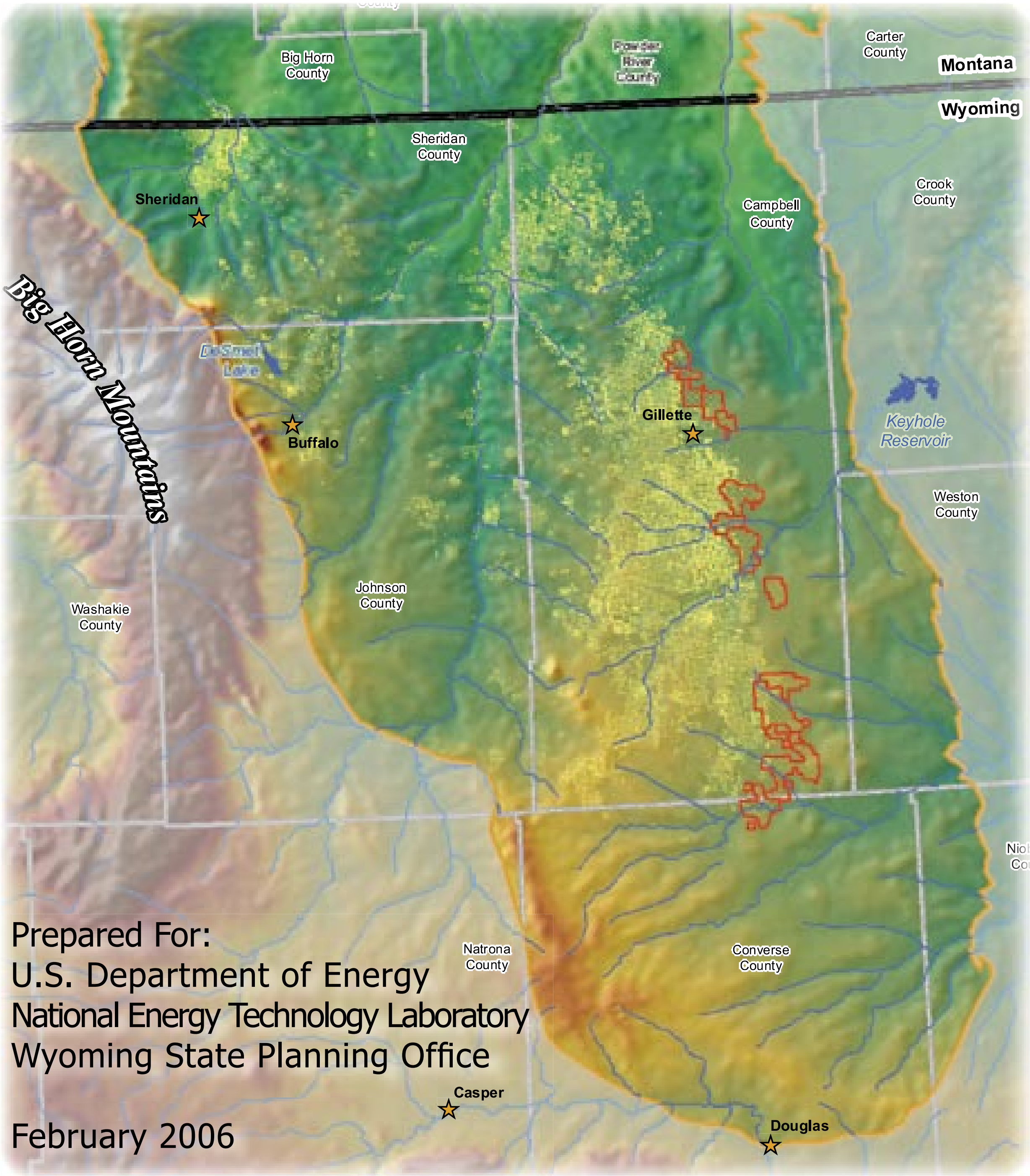
Feasibility Study of Expanded Coal Bed Natural Gas Produced Water Management Alternatives in the Wyoming Portion of the Powder River Basin

Phase II



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ACRONYMS AND ABBREVIATIONS

ASR	Aquifer Storage/Recovery
bls	Below Land Surface
bbl	Barrels
bpd	Barrels per Day
CBNG	Coal Bed Natural Gas
DOE	United States Department of Energy
EA	Environmental Assessment
EC	Electrical Conductivity
EPA	Environmental Protection Agency
MBER	Montana Board of Environmental Review
MDEQ	Montana Department of Environmental Quality
mg/L	milligrams per liter
MOU	Memorandum of Understanding
NA/RC	North Antelope / Rochelle Complex
NEPA	National Environmental Policy Act
OTA	Office of Technology Assessment
PM_{10}	Particulate Matter with diameter of 10 microns or less
ppm	Parts per Million
PRB	Powder River Basin
RCRA	Resource Conservation and Recovery Act
RMP	Resource Management Plan
SAR	Sodium Adsorption Ratio
SDWA	Safe Drinking Water Act
TCF	Trillion Cubic Feet
TDS	Total Dissolved Solids
UIC	Underground Injection Control
USDW	Underground Source of Drinking Water
USGS	United States Geological Survey
$\mu g/m^3$	Micrograms per cubic meter
WDEQ	Wyoming Department of Environmental Quality
WOGCC	Wyoming Oil and Gas Conservation Commission
WPDES	Wyoming Pollution Discharge Elimination System
WSEO	Wyoming State Engineer's Office
WWDC	Wyoming Water Development Commission

DISCLAIMER

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Section 1: Introduction

The Phase II report of this Feasibility Study describes in detail the benefits and costs of the most attractive alternatives for managing produced water from CBNG development in the Wyoming portion of the Powder River Basin (PRB). The State of Wyoming initiated this study to highlight those water management technologies that appear to be feasible in terms of technology, economics, and existing regulations. The Governor's Planning Office coordinated this Feasibility Study with the help of representatives from Wyoming's CBNG industry and relevant state regulatory and development agencies. The State of Wyoming is particularly intent to concentrate on those alternatives that have the capability of managing large volumes of water that might be produced from Big George and similar coals in the Wyoming portion of the PRB.

Some of these management alternatives such as injection wells may be utilized by industry in a fairly short timeframe while other alternatives such as long pipelines will require several years of lead-time. Both categories of alternatives will be discussed in this report.

Purpose of Feasibility Study

The purpose of this Feasibility Study Report is to identify water management alternatives with the best chances of managing the large volumes of water being produced from Big George and similar coal seams in the PRB. Produced water management has always been an important aspect of the CBNG industry in the PRB and it could become more important if proposed new water standards are adopted in the State of Montana. Watersheds such as the Powder River that extends north into Montana could be affected to the point that common forms of water management can no longer be used in Wyoming. This Feasibility Study was initiated with an eye on the proposed Montana standards. The study aims to highlight those water management options that are compatible with the new standards as well as existing Montana and Wyoming standards.

Forecast Effects and Timing of Proposed Montana Regulatory Changes

CBNG development on the Tongue, Powder, and Little Powder watersheds can be severely affected by the planned Montana water standards. If the State of Montana adopts stricter surface water standards, surface discharge, infiltration impoundments, and existing methods of water treatment will no longer be possible within the Tongue, Powder, and Little Powder watersheds. These new standards could have the effect of shutting in current CBNG production and will certainly have a dampening effect on planned, new development in Wyoming. Even if the operator has an acceptable, primary method for managing his produced water, the operator will be depending upon treatment, storage, or discharge as a back-up method. If these options are no longer possible, the operator may have no other choice but to abandon the CBNG project. In order to prevent such loss of resource development, the State of Wyoming initiated this Feasibility Study.

The Montana Board of Environmental Review (MBER) has held a number of public hearings on the proposed new regulations. The Board members are considering these rules and comments by private citizens, residents of the areas where CBNG development is taking place and is expected to take place, as well as CBNG developers. The MBER is due to vote on these regulations on March 23, 2006. If the new regulations are adopted, the Montana Department of Environmental Quality (MDEQ) could have them in-place as early as April 7, 2006 (Hallsten, 2006). At that time the regulations could be challenged by the Montana State Legislature. Whether or not they would be binding on operations within the state of Wyoming by that early date is unknown. The new regulations will be incorporated into a new Memorandum of Cooperation between the Wyoming Department of Environmental Quality (WDEQ) and the MDEQ although the specifics of the new regulations may not be in force until their adoption by the EPA and even then may be contested in Federal District Court.

Section 2: Feasibility of CBNG High Priority Water Management Alternatives

Introduction

The following five management alternatives have the potential to manage high volumes of water. The costs and benefits of each alternative will be discussed below. When determining the applicability of each option, the test will be the ability to manage the 1.5 million bpd of CBNG produced water. Of special importance is the approximately 0.5 million bpd produced from the Big George coal seam in the PRB. Big George water quality is characterized by 53 samples taken from separate CBNG wells and supplied to the USGS. Water quality is summarized in Figures 1 and 2 below while the data set is included in Appendix A at the end of this report.

Figure 1: Salinity of Big George Water as Expressed by Electrical Conductivity from 53 Producing Wells in the Powder River Basin

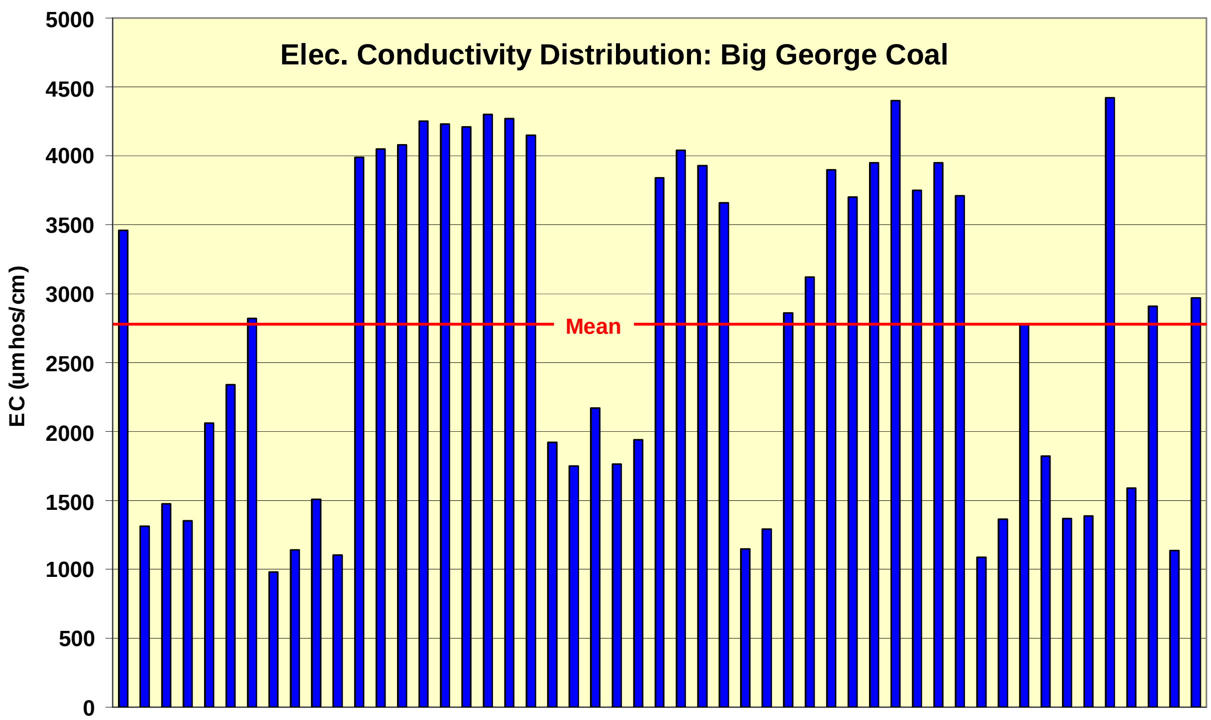
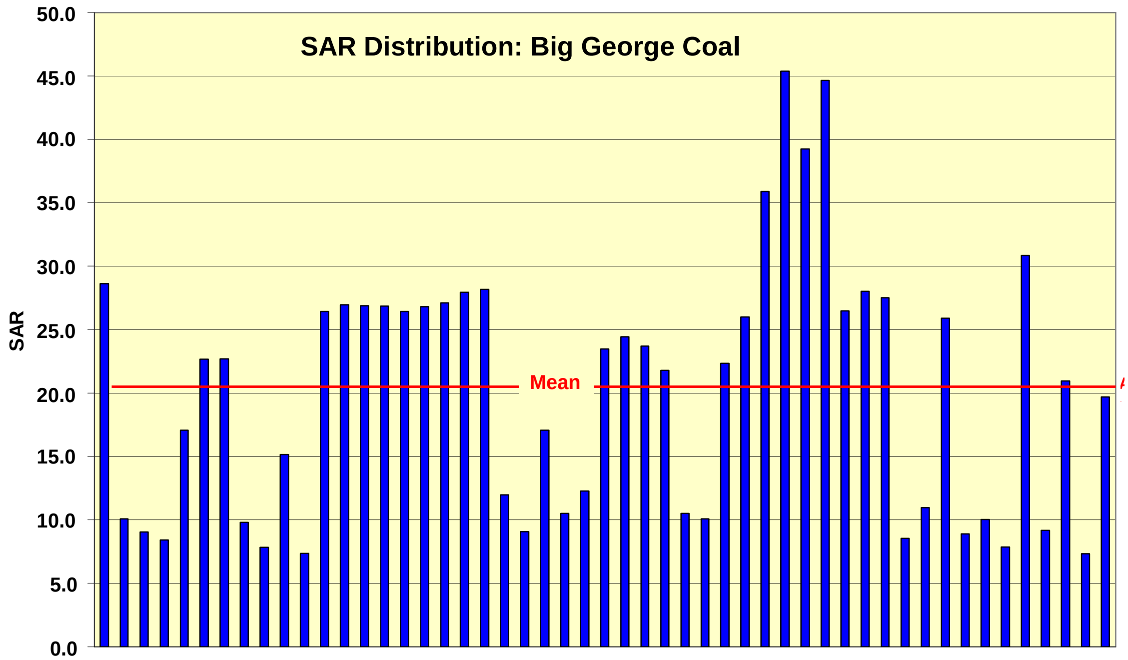


Figure 2: Sodium Adsorption Ratio of Big George Water from 53 Producing Wells in the Powder River Basin



Water in the Big George shows variability but can be described as higher in salinity than average and slightly higher than average for SAR. Water quality (mean salinity: 2800 µmhos/cm, TDS calculated at approximately 2140 mg/L, and mean SAR: 20.3) suggests that while some beneficial uses can be found, Big George water has the capacity to degrade some high quality surface water. Salinity is the total dissolved salts within the water and can determine the suitability of the water for some uses such as drinking water for livestock, crop irrigation, and some industrial applications. SAR is an indirect measure of sodium in relation to calcium and magnesium; SAR determines the likely impact of water on the physical properties of soils, especially for irrigation and direct discharge. Concentration of other constituents can affect the suitability of water for other uses such as aquaculture or industrial processes. Feasibility to use untreated and treated Big George water in the following management alternatives will be included in each discussion.

Alternative 1: Treatment and Discharge or Beneficial Use

Description: CBNG water can be improved in quality through the use of technologies to reduce salinity; inorganic ions are removed from solution although no constituents are targeted. A number of treatment technologies are available and several are currently used on a limited scale by CBNG operators. Costs, efficiencies, and infrastructure requirements will vary but the common trend is increasing costs with increasing salinity of the feed-stock and decreasing salinity of the outflow. Treatment facilities can be expensive to construct and operate.

Potential Benefits and Synergies with Other High Priority Alternatives: Treated water is compatible with all the other high priority alternatives although such high quality water may not be needed for every alternative. Discharge to public reservoirs filled with high quality surface water such as Glendo or Grayrocks would probably require treatment of most or all of the Big George water prior to discharge. The treated water could be rendered compatible in terms of TDS and SAR to the reservoired water if it can be delivered to the reservoir without interaction with soil or bedrock.

Political and Public Perception Barriers and the Potential for Non-governmental Organization (NGO) Lawsuits: Treatment facilities can involve invasive infrastructure, especially if large volumes of water need to be processed. A large facility to treat 200,000 bpd of Big George water is eight times the largest operating treatment plant and three times the capacity of any existing plant in the basin (Thomas, 2006). In addition to the buildings, several large overflow, storage, and treatment ponds would be needed on the location. If the plant is 95 percent efficient, approximately 10,000 bpd of waste brine would be generated; the approximately 100 truck loads of brine would need to be sent out to a Class I disposal well every single day. The constant truck traffic could be objectionable to local residents.

The Wyoming Department of Game and Fish is sensitive to both water quality compatibility and flow rate impacts caused by discharge of CBNG water (Mavrakis, 2005). Sportsmen may protest discharges of treated water during times when fish eggs or hatchlings are vulnerable. In addition, ranchers and farmers may object to changes in water flow rate and quality during periods of irrigation.

Water treatment facilities have been a part of the CBNG industry in Wyoming for at least five years but few facilities are currently in use. While public opposition has not been encountered, a large increase in the number and size of the facilities may lead to more protests although this is likely to be only on aesthetic grounds such as noise, traffic, and visual presence.

Regulatory Feasibility and Barriers: New water treatment plants will need an appropriate construction permit, Wyoming Pollution Discharge Elimination System (WPDES) permit, and Wyoming Oil and Gas Conservation Commission (WOGCC) pit permit. New technologies will apply for a WDEQ pilot plant temporary permit that can be converted into a statewide construction permit after at least 12 months of operating data can show the stability and effectiveness of the facility. A statewide permit will facilitate construction of any number of plants with the same design while each facility would require its own discharge permit.

WPDES discharge permits are written to minimize impacts to the environment from discharged water. Discharged water can be matched to the receiving water quality to eliminate impacts due to water quality contrasts. By mixing treated and raw water, the discharged water can be changed seasonally to match the changing water quality of the receiving stream or reservoir. In spite of this compatibility of quality, the large volume of discharge water may enlarge or even "perennialize" the receiving stream or by filling the reservoir, the discharge may perennialize the outflow below the reservoir. If the once intermittent or ephemeral stream or outflow now has water in it most of the year, this will change the conditions for plants and animals within the riparian area. And when the riparian environment is affected, the ripple effect will be wide-ranging. Wildlife that live most of their lives away from the stream but must come to the stream for water will now be open to all the aspects of the new riparian zone. Prairie dogs that den a half-mile or more from the stream could now be predated by hawks that live in thriving new cottonwood trees along the newly perennial stream.

If the receiving water body is enlarged it may exert distinct changes to the riparian zone along the water body for a considerable distance. If flow is increased, localized erosion and sedimentation will also be increased, perhaps to such a degree that invertebrates and vertebrates may be directly harmed. Some fish species may be impacted by the loss of available habitat and loss of suitable breeding sites. Others may be stressed by the increase or decrease in water turbidity. Still other species may be impacted by the increase in temperature within the stream caused by the discharged water. Discharges from high volume treatment plants, as proposed in this alternative, may threaten riparian biota and stream bank geography.

Most citizens have tended to look upon the few treatment plants as good for the environment. If 20 or 50 times as many plants are to be constructed, citizens may be less encouraged and may begin to protest construction permits.

Technical Feasibility and Compatibility of Big George Produced Water: Treatment facilities can successfully utilize Big George produced water to output high quality water and waste brine (Cline, 2006). CBNG produced water can contain iron bacteria and trace amounts of oil and grease; these constituents can degrade the treatment facilities and cause early failure of the system. Treatment efficiencies for one facility are illustrated in Table 1 below that lists site-specific untreated Big George water quality and the quality of unblended treated output.

Table 1: Pre and Post-Treatment Water Quality for Big George Produced Water (Source: Beagle, 2006)

Constituent	Pre-Treatment (Input)	Post-Treatment (Output)
EC (μhmo/cm)	4,000	300 to 500
TDS (mg/L)	2,620	200 to 325
Sodium (mg/L)	900	70
SAR	25	5

Post-treatment water quality will vary from facility to facility and by quality of the input water. Output water of this quality may be appropriate for some of the produced water management alternatives. Other alternatives may not require water of such high quality, in which case the treated output could be blended with untreated water to match the requirements. Other management alternatives may require water of higher quality; in that case, the treatment process will need to be amended.

Depending upon the beneficial use, the output water may need subsequent treatment. If the water is to be used for irrigation, the SAR may need to be adjusted. This adjustment is a delicate balancing act of adding calcium and magnesium ions to the water to lower SAR while keeping the TDS within the required limits. This is frequently done by adding gypsum (Ca, $MgSO_4$) to the output in a lined holding pit (Olson, 2005). But output water from the treatment facility is an excellent inorganic solvent and if too much gypsum is dissolved in the water, the TDS could be in excess of requirements. Care will need to be taken to balance SAR and TDS for the particular beneficial use.

Economic Feasibility Including Transportation Costs and Treatment Costs if Required: Site-specific treatment costs will depend upon the quality of output water needed. If medium quality water will suffice for cooling water, for example, perhaps only 50 percent of the Big George water will need to be treated and the blend will be appropriate for the beneficial use. If higher quality output is needed, more of the water will need to be treated prior to mixing and discharge. Quantity and quality of the input produced water will also affect costs. Table 2 is a compilation of capital and operation and maintenance costs for water treatment facilities in the PRB (DOE, 2006). Data for this table was received from operators in the PRB and variability was taken into account. For example, one operator noted that high quality water from the Wyodak coal can be treated for approximately $0.08/bbl while Big George water can be treated for approximately $0.25/bbl in large volumes (Doll, 2005). The $0.13 to $0.33 per bbl of treated water will vary from facility to facility but is a good estimate (Likwartz, 2006). Capital costs will also vary with the size of the facility and water production from each well.

The costs in Table 2 do not include transportation of produced water to the plant or transportation of the treated output water to its point of discharge or point of use. Transportation will need to be by way of truck for small volumes or pipelines for large volumes. Transportation in streams or drainages cannot be done without degrading the water quality of the output water. The large volumes that are being envisioned by this Feasibility Study would require that transportation be done via pipeline sized to the capacity of the treatment plant. Pipeline costs will vary by the size of the line and its length as well as other factors such as terrain to be crossed and net change in elevation.

Table 2 does include some costs for disposal of waste brine, although this will vary by site and process. In the PRB, waste brine is taken from treatment plants to a commercial disposal well that charges approximately $1.00 per bbl to dispose the brine. Total disposal costs for the brine may be approximately $1.50 per bbl and can be allocated at the rate of approximately $0.07 to $0.15 per barrel of treated water. Other ways of managing this waste brine are discussed below.

Table 2: Estimated Water Treatment Costs for CBNG Water in the Powder River Basin (Source: DOE, 2006)

	Water Disposal Costs	
	Capital Costs/Well	O&M Costs/Bbl.*
Water Disposal		
A. Surface Discharge	$1,500	$0.04
B. Infiltration Impoundment	$20,900	$0.10
C. Shallow Re-Injection	$36,400	$0.10
D. Reverse Osmosis w/ Trucking & Disposal of Residual Concentrate	$72,300	$0.31**
E. Ion Exchange	N/A	$0.13–0.33**

**Per barrel of water produced for a "typical" CBM producing 320 barrels per day (average) during the first two years.*

***Per barrel of water treated*

**** Per barrel of water treated, based on industry-provided "turn-key" prices depending on inflow water quality.*

Legislative Implications of the Alternative with Emphasis on Opportunities for Relief: Legislation could mitigate one of the costliest aspects of the treatment alternative – disposal of the waste brine. Waste brine comes out of the process at a concentration of ten to 50 times the input produced water – approximately 25,000 to 100,000 mg/L for Big George water (Olson, 2005). This concentration is quite similar to conventional oil and gas produced water in the PRB (USGS, 2006); water produced from the Muddy/Newcastle Formations varies in quality from over 50,000 mg/L to less than 2,000 mg/L; water produced from the Nugget Formation ranges from 50,000 to 70,000 mg/L; and the Minnelusa Formation contains concentrated formation water in excess of 150,000 mg/L. The pH of the treatment waste water can, however, be highly acidic and may need to be treated prior to disposal (Beagle, 2005).

Currently wastes from the treatment of produced water are classified as an industrial waste that must be disposed into a commercial Class I (Industrial waste) disposal well. If the waste brine could be categorized as an oil and gas waste it would have a source-exemption from RCRA Subtitle C regulations and could be put into a Class II disposal well. The source-exemption is independent of the characteristics of the waste but depends instead on the wastes being "intrinsically derived from primary field operations associated with the exploration, development, or production of crude oil and natural gas" (EPA, 1995). A list of specific exempt wastes was published by the EPA and includes "Constituents removed from produced water before it is injected or otherwise disposed of" (ibid). Clearly a waste brine extracted from CBNG produced water could qualify as an exempt waste by the EPA's publications (EPA, 1988 and EPA, 1993). Recently, the EPA made the determination that treatment waste brine from a Reverse Osmosis facility treating CBNG water from the San Juan Basin was an exempt waste (Brown, 2006). The EPA made the determination based on the fact that the waste brine had the same chemistry as the produced water and only the concentration had changed. The determination is included in Appendix B at the end of this report. BP America requested the determination from EPA Headquarters in order to counter the non-exempt determination made by EPA Region 6 (Brown, 2006). BP's argument centered on the fact that the waste brine was intrinsically derived from primary field operations associated with the exploration, development, or production of natural gas, in this case CBNG. Their argument was based on the waste source, not waste characteristics. The determination made by EPA would appear to apply to RO treatment, but not to Ion Exchange treatment such as EMIT.

Exemption from RCRA Subtitle C does not automatically confer exemption from all federal and state regulations. The WDEQ has determined that the waste brine generated from an EMIT CBNG produced water treatment facility is an industrial waste, as written into the EMIT Statewide Construction Permit (Beagle, 2005). A similar determination has been made for the other produced water treatment facilities in the state (Thomas, 2006). The same is true for the Pinedale Field in western Wyoming where Newpark Industries takes produced water from Shell Western E&P, treats it in a modified RO facility, and disposes the waste brine into a commercial Class I disposal well.

The WDEQ determination was driven by a letter received from Stephen Tuber, the EPA Deputy Administrator in Region 8 in Denver. This letter includes the following statement "EPA has concluded that the waste in question, the brine discharged from the Higgins Loop, is waste from a treatment process that is not intrinsic to exploration and production operations." It might be argued that indeed water management is a vitally important intrinsic element of many CBNG projects within the PRB. Some basins produce very little water as part of CBNG development but the PRB is not one of those basins. In the PRB, almost every well produces large quantities of water from the first day of production and it is the operator's ability to manage this water safely and economically that will determine his success (Williams, 2005).

Legislation could drive a change in WDEQ's determination from industrial waste to oil and gas exempt waste. It would then be possible to allow the WOGCC to permit the disposal of these wastes into Class II disposal wells by way of a Memorandum of Understanding (MOU). The MOU would allow mixing the treatment waste brine with any E&P produced water prior to injection into a private or commercial Class II disposal or secondary recovery well. Benefits would include allowing the operator to handle the waste brine in the same manner he handles the rest of his produced water with the same infrastructure. Transportation to the injection well would likely be via pipeline rather than truck, resulting in reduced traffic, reduced noise, and reduced dust. Overall costs for treatment would certainly be less than current costs (Olson, 2006). Legislative incentives could involve guaranteed loans for the pipeline system or assistance for condemnation of the right-of-way.

Timing Issues Including Sensitivity Analysis: This alternative is in use at the present time in the Wyoming portion of the PRB; several pilot-test permits have been written and one statewide permit (Thomas, 2006). Operational history data exists that suggest that the installation of these facilities can be done in a short time. There are, however, no facilities that approach the size proposed under this and other management alternatives. A facility able to treat over 200,000 bpd could either be a single unit with a completely new design or a collection of several smaller, existing design units ganged together. The former would likely take advantage of economy-of-scale factors while the latter could be constructed much more quickly. Permitting and construction schedules will be especially sensitive to design changes. Any estimation of the extra time required would be highly speculative.

Alternative 2: Discharge to Public Reservoirs

Description: Long distance transfer of Big George produced water can bring this resource to public reservoirs and watersheds in need of water. During this period of prolonged drought across the state, surface water distribution has changed, causing some environmental disruptions and ecological changes. If long pipelines could be constructed from the heart of Big George production to one or several of these watersheds or reservoirs, the beneficial use would be considerable. In order to control the discharge and maintain the ability to discharge year-round, the discharge points need to be located in storage facilities, either existing reservoirs or new impoundments.

Several public reservoirs exist across the PRB:

- Lake De Smet is an off-channel reservoir constructed between the upper reaches of the Powder River and the Tongue River watersheds. Approximately 180,000 AF of active storage can be accomplished at the reservoir. Water is pumped into the reservoir from Piney Creek, Rock Creek, and Clear Creek as well as a small amount of natural drainage into the reservoir from nearby small streams such as Shell Creek. Outlet is either into Clear or Piney Creeks. Both of these are tributary to the Powder River north of the town of Arvada. Water is used for recreation, irrigation, power generation, and for maintaining flow in Piney and Clear Creeks in time of drought. At the present time the reservoir is essentially full (Dixon, 2006). The Cities of Buffalo, Sheridan, and Gillette have considered using water from Lake De Smet to meet their future water supply needs.

- Keyhole Reservoir is an on-channel reservoir constructed on the Belle Fourche River as a source of irrigation water and flood control. The reservoir is subject to the Belle Fourche River Compact and the water resources are allocated 10 percent to Wyoming users and 90 percent to South Dakota users (BOR, 1998). The reservoir has approximately 185,000 AF of active storage. As of January 12, 2006, the active storage capacity was 37.4 percent full (BOR, 2006b).

- Glendo Reservoir is a reservoir located below Douglas on the North Platte River. The reservoir has an active capacity of approximately 790,000 AF. Flood control, power generation, irrigation, and fishery maintenance are all important aspects of reservoir storage. As of January 19, 2006, the reservoir's active storage was 50.6 percent full (BOR, 2006a).

- Grayrocks Reservoir is constructed on the Laramie River upstream from its confluence with the North Platte. The main function of this reservoir is to supply a year-round source of cooling water for the Laramie River Station power plant. This approximately 104,000 AF reservoir has been heavily impacted by the extended drought and the plant must supplement the reservoir with groundwater from nearby wells. As of January 16, 2006, the reservoir was approximately 25 percent of active capacity (Bennett, 2006).

Each of these reservoirs could use supplemental water for fill and to maintain adequate outflow. The compatibility of Big George water is, however, an issue.

Potential Benefits and Synergies with Other Alternatives: Several of these reservoirs have need for water in order to maintain primary functions. The Grayrocks Reservoir, for example, is at such a low point due to the current drought that the Laramie River Station, a 1,665 Mega-watt power plant, is having to use secondary sources of cooling water (Schultz, 2005). If these conditions persist, the plant may have to re-engineer its cooling configuration. If this plant must depend upon groundwater for cooling, this could result in a depletion of local groundwater resources. On the other hand, if Big George water could be supplied to the reservoir on a year-round basis, higher quality local water could be preserved for higher uses such as drinking water or animal husbandry. At the same time, if reservoirs can be kept nearer to full-pool status, more aquatic habitat and more stable habitat will be available within the reservoir. In addition, if CBNG water could be used to augment the reservoirs, less water would need to be diverted from area streams, thereby preserving water flow and habitat in those streams.

A long pipeline running from the Big George producing area to either of the reservoirs on the North Platte would have the advantage of passing nearby municipalities such as the City of Wright whose City Council foresees the need for additional water supply (Kingan, 2006). They plan to add a fifth water supply well this winter. Access to the Big George pipeline may allow them to take some of this water either in the raw form for irrigation or after treatment for drinking water.

A pipeline running from the Big George area to Keyhole Reservoir would cross the area of coal mines and power plants to the north of Gillette. Both types of facilities could take advantage of the Big George water resource in the pipeline. Pipelines running from the Big George area to both Keyhole Reservoir and Lake De Smet might very well approach county facilities where road maintenance crews might offload water to apply to county roads as dust abatement.

Political and Public Relations Barriers and Potential for NGO Lawsuits: Replenishing reservoirs is a high order of beneficial use that should be perceived by the public as suitable and applicable. While it does indeed represent the removal of water from, for instance, the Powder River watershed to the N. Platte River watershed, this water in the Big George seam is so deep that it is unlikely to be tapped by ranchers and farmers in water supply wells. At these depths, the CBNG water does not constitute a valuable water resource. It needs to be emphasized that the produced water that will be piped into the reservoirs under this alternative is the remainder after the local land owner is given his share of water for local use, either for managed irrigation or cattle ranching; the local rancher will not be denied this resource.

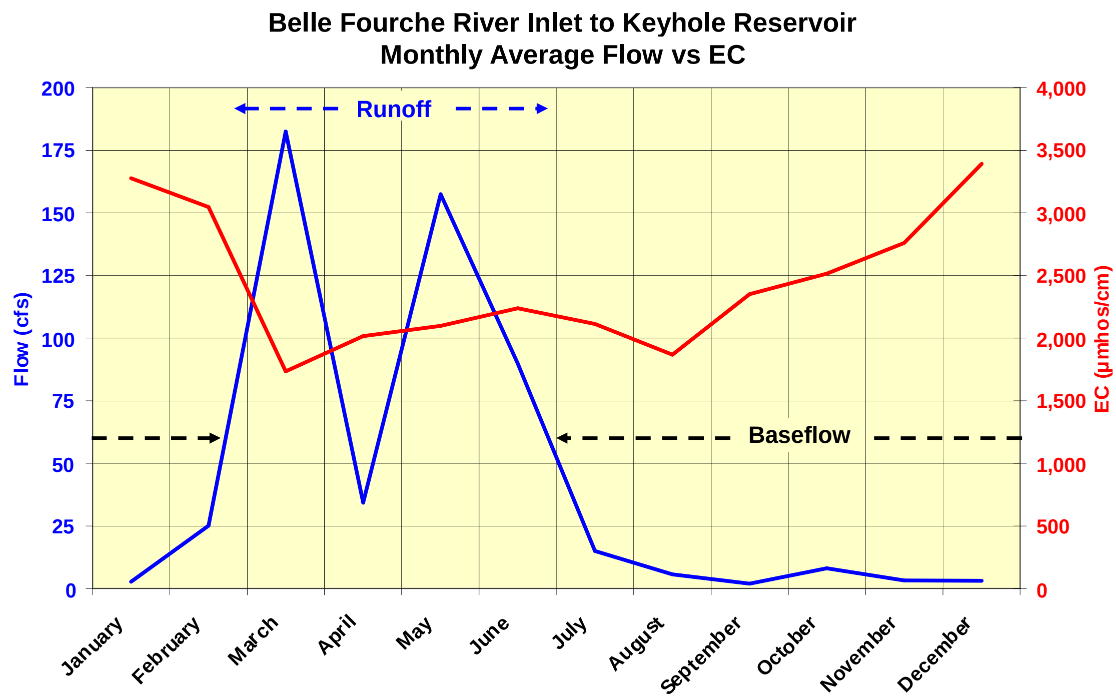
Regulatory Feasibility and Barriers: Discharges will need to meet the requirements of the Wyoming NPDES permitting conditions. In order to receive a permit, the operator will need to demonstrate that the discharge will not degrade the receiving water below its existing classification. Classification of the water bodies will need to be done prior to making application for the discharge permit. The quality of Big George produced water is below that of the reservoirs. There may be insurmountable barriers to discharging raw Big George water and any discharges may need to involve at least partial treatment and blending of the Big George water.

Technical Feasibility and Compatibility with Big George Water: The feasibility of discharging Big George produced water to these reservoirs will depend upon water quality compatibility. Big George water is not as high quality as water from many shallower coal seams. Its average salinity as measured by TDS is approximately 2100 mg/L while TDS measured by EC is approximately 2800 μmhos/cm, but it ranges considerably; Big George water quality is described in the introduction above.

Surface water in the reservoirs varies with the season; snow melt and precipitation leads to more water and higher quality water. If no water is falling as rain or snow, only baseflow is delivered to the streams and reservoir and quality is lower. Seasonal summaries of water quality are presented below for the reservoirs.

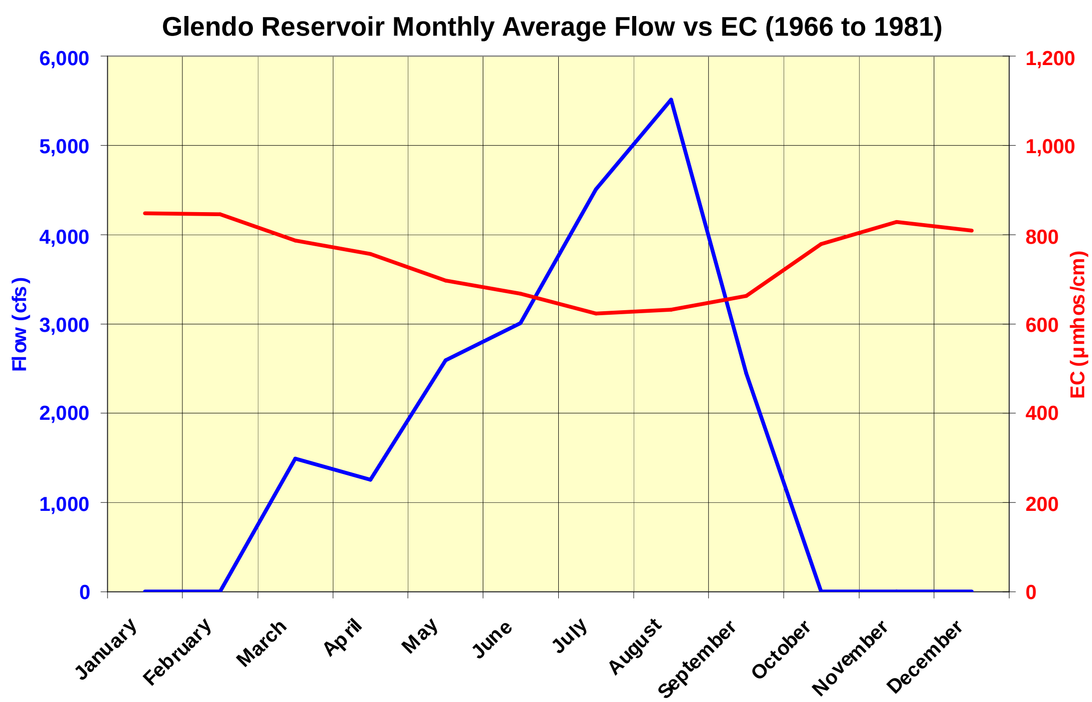
- **Keyhole Reservoir**: This reservoir receives water from the Belle Fourche River; water quality (Figure 3) varies by season with quality improving marginally as runoff increasingly brings meteoric water into the river and the reservoir. As seen in the graph, water quality in the Belle Fourche as it enters the reservoir during most of the year is of similar or better quality than Big George average quality. During that part of the year when flow is minimal (Baseflow), water quality is lower. During periods of maximum flow (Runoff), quality is consistently higher. Preliminary water analysis suggests that approximately 50 percent of the Big George water may need to be treated and blended with raw water to achieve an overall EC of approximately 1650 μhmo/cm. Detailed analyses of water in the reservoir will need to be done to calculate treatment plans and possible barriers to discharge such as trace metal content or SAR of the Big George water.

Figure 3: Water Quality Entering the Keyhole Reservoir (Source: USGS, 2006).



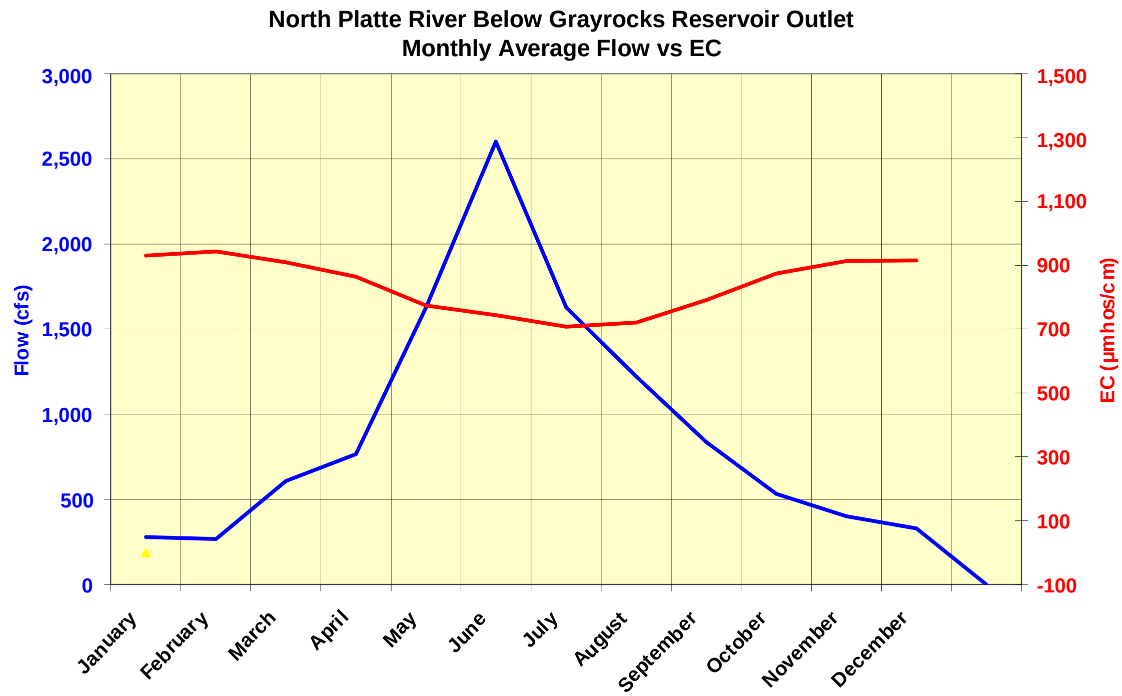
- **Glendo Reservoir:** Water quality can be approximated from water analyses at the North Platte River USGS station at the inlet to the reservoir. This is presented in Figure 4. Water in the North Platte shows slight water quality variation with the seasons and its quality is consistently high. Big George produced water will need to be treated in order for it to approach the quality of water in Glendo Reservoir. It is unclear what portion of the total Big George stream will need to undergo treatment in order to avoid impact to the river.

Figure 4: Water Quality Entering the Glendo Reservoir (Source: USGS, 2006).



- **Grayrocks Reservoir:** Figure 5 graphs the water quality in the N. Platte River below the Grayrocks Reservoir. This gauging station can be used as an approximation of water in the reservoir, which is built on the Laramie River upstream of the confluence with the N. Platte. Water quality is quite similar to water above the Glendo Reservoir; it is clear that water in the North Platte is consistently high in quality. Treatment data on Big George water suggests that at approximately 90 percent of the discharged water will need to be treated and blended in order to achieve an EC of approximately 710 µhmo/cm. The details of the treatment regimen will depend upon the water quality in the reservoir and the quality of the Big George mix.

Figure 5: Water Quality Below Grayrocks Reservoir (Source: USGS, 2006).



- **Lake De Smet:** There is little water quality information from the upper reaches of the Powder River watershed where Lake De Smet is located. The single samples taken from the reservoir and the limited sampling done by Fidelity Exploration and Production suggest that the water is very high in quality (Williams, 2005). Limited sampling data are summarized in Table 3 below. This is consistent with the location of the lake close to the Big Horn Mountains where snow melt and rain contribute very high quality meteoric runoff water. It is probable that Lake De Smet contains water even higher in quality than the two reservoirs (Glendo and Grayrocks) in the North Platte watershed. More detailed water quality analysis of the reservoir will need to be carried out throughout the year and at various locations and depths. The water quality survey will determine the compatibility of Big George water with the reservoir. It is likely that 100 percent of the Big George water discharged to this reservoir may need to be treated.

Table 3: Water Quality in Lake De Smet Reservoir (Source: WWDC, 2003)

SAMPLE DATE	TDS (mg/L)
October 1959	660
June 1960	660
August 1960	690
March 1961	594
April 1963	600
November 1963	582
October 1964	524
January 1966	640
February 1972	336
June 1972	365
August 1972	288
October 1972	466
August 1975	532
June 1976	655

The largest technical barrier to using CBNG produced water for augmenting reservoirs may be the inconsistent volume and short duration of the supply of produced water. CBNG wells have a limited well life and produce at a declining rate over time; the reservoir managers may not want to make a significant investment if the volume of water to be supplied is not significant or is only a short term supply. Big George and other deep thick coal seams may produce large volumes of water over a longer time but the coals will eventually deplete. The time frame may be five years or ten years. The depletion rate will need to be factored into the evaluation of this management option.

Economic Feasibility Including Transportation Costs and Treatment Costs: Pipelines will be required to transport the water from areas of Big George production to the reservoirs. Discharge to drainages would not be suitable as the discharge of raw Big George water might impact large stretches of shallow alluvium aquifer and discharges of treated water will result in the degradation of that water. Delivery and beneficial use of the water may best be accomplished by pipelining the raw water and treating the water to the required level at the use end although this issue will require a site-specific analysis. While a large, centrally located treatment facility may have a sizeable economy of scale, the smaller facilities could be individually tailored to the water quality requirements of the end use. Waste management from a single large treatment facility may be easier than from several small plants, but the single large plant may be unacceptably intrusive to rural residents.

Pipeline construction costs may average $43,000 per inch mile. A 20-inch pipeline would then average approximately $850,000 per mile and would be able to transfer over 200,000 bpd of water. During five years' time, this pipeline would have the capacity to transfer approximately 365 million bbls of Big George water. If the pipeline system were 100 miles of total length, costs would be approximately $85 million or an average of $0.23 per bbl of water transferred over five years. Operations and maintenance may add $0.05/bbl to the cost. The total of approximately $0.28/bbl will depend on the specifics of pipeline location.

Treatment costs will be determined by the quality of the effluent discharging to the reservoir. Effluent quality will be calculated by way of water quality modeling performed for the specific reservoirs. Regardless of the exact proportion of the CBNG water that will need to be treated, a large volume will be treated - perhaps 200,000 bpd. The economy of scale may bring the costs down to the low end of the DOE cost estimates shown in Table 2 above. Treating 200,000 bbls will cost approximately $26,000 per day, or nearly $9.5 million per year.

Legislative Implications of the Alternative with Emphasis on Opportunities for Relief: Interbasin transfer of groundwater resources is an issue with legal aspects beyond the scope of this feasibility study. There are questions about the transfer of groundwater and its relevance to interstate water compacts (Tyrrel, 2006). The Yellowstone River Compact (1950), the Belle Fourche River Compact (1944) and the North Platte River Decree (1945) concern only surface water and not groundwater. It would be the task of the state to prove that the transfer of groundwater would not impact surface water in these watersheds. These questions do not appear to be insurmountable and can be dealt with by documentation that only groundwater will be transferred and surface water resources will not be involved.

Interbasin transfers could be the subject of protests from water users in the originating basins such as the Powder River watershed where the majority of Big George water is being produced. Protests from individual ranchers, communities, and irrigation districts could become barriers to the implementation of this alternative. Enabling legislation could be put in place prior to permitting and construction that will allow transfer of CBNG produced water for a bona fide beneficial uses such as reservoir fill, cooling medium at power plants, and dust control on coal mine haul roads and county roads. Legislative incentives could also involve guaranteed loans for the pipeline system or assistance for condemnation of the right-of-way.

Timing Issues Including Sensitivity Analysis: Permitting and construction schedules will depend upon location and the length of the system. Pipeline contractors will be familiar with the scheduling problems involved and uncertainties will likely be minor.

The discharge of either raw or treated water to reservoirs may require an Environmental Impact Statement (EIS) before operations can happen. It will be this NEPA planning process that introduces uncertainties into any schedule that includes discharge of water from federal minerals. Mandated public participation in the EIS process can be drawn out by the need to educate the public, solicit public comment and address public concerns. Modeling will need to be accomplished to forecast the impacts to the individual reservoirs and to the watersheds that surround the reservoirs. Possible impacts to be evaluated will include biota within the reservoirs and rivers as well as increased erosion and sedimentation caused by augmented stream flow in the various watersheds. Discharge permits may require consultation with US Fish and Wildlife Service personnel in order to determine possible impacts to threatened, endangered, and sensitive species in Wyoming waters as well as those in adjoining states. Several major EIS documents have been completed in the PRB in the past five years; therefore the uncertainties are well understood. The EIS, if required, will very likely require at least 18 months to complete.

Alternative 3: Use in Municipal Water Supplies

Description: Some municipal water supplies in Wyoming could shortly become strained from over appropriation and recent drought conditions. Cities are looking to supplement their water supplies by adding wells or looking to other surface reservoirs. For municipal water supplies, CBNG produced water could be used to augment traditional supplies. This alternate supply of water could help to promote aquifer recharge and reduce demands on other more traditional water supplies from both surface and groundwater sources. CBNG produced water that may be of a slightly lesser quality, but still of high enough quality to be usable, could be used for non-potable purposes, used as make-up water in wastewater treatment activities, or used in reclaimed water reuse applications instead of using drinking quality water.

CBNG produced water could be used to augment municipal water supplies both for potable and for non-potable uses. High-quality or treated produced water that meets drinking water standards could be used for human consumption. This water could be collected at a CBNG water management facility then transported to a municipal supply facility for treatment and subsequent distribution. Depending on the circumstances such as quality of the produced water, treatment requirements, and other factors, using produced water as a sole source may be feasible for a certain portion of the municipality, in mixed distribution with the existing supply, or as a seasonal or period augmentation of over appropriated supplies. Additional infrastructure would be needed for the transportation of produced water to the municipality. The potential for the distribution of lesser quality produced water for non-potable uses within a municipality may be greater than potable use. The potential non-potable uses for CBNG produced water in a municipality include the use of a dual water system. In addition, municipalities could use produced water to supply water to fire hydrants, irrigation, street cleaning equipment, and certain industries including commercial car washes. Non-potable produced water can also be collected at the CBNG field and distributed directly to the municipality. A city with a non-potable/potable dual water system would be ideal for using the lesser quality produced water, but installation of such a system for a city with a single distribution system would most likely be cost prohibitive.

Potable water use varies by municipality and by season. Peak water use in the area occurs in the summer in the months of July and August (Allgood, 2006). During these dry summer months, especially in recent times of drought, a city would benefit from augmented water supplies supplied with high quality or treated CBNG produced water.

Towns and cities in Wyoming use surface water and/or groundwater for their supply. Groundwater aquifers may be located in the Fort Union, Fox Hills, or deeper units. A survey of five cities in the PRB was performed and summaries of these city's water supply systems and uses are given below. Table 4 below presents a tabular summary of all the city data.

- The City of Buffalo uses both groundwater and surface water. They have one well that is used to irrigate the golf course and the school. Their drinking water supply comes from Clear Creek and the Tie Hack Reservoir. The reservoir can store 2425 ac-ft of water and flows into Clear Creek. Two holding ponds are located at the water treatment plant; both are fed via a pipeline from Clear Creek. Treated water is then piped from the treatment plant to the city. Buffalo was the only city contacted that had a dual supply water system, with the raw water system coming from the well and used only for irrigation. The city has a limited allotment of water and foresees that they may need to seek additional supplies as the city's water needs grow (Allgood, 2006). They have not considered using CBNG as a source to date. Their annual water use in 2005 was 422 million gallons (10 million bbls). Their water system information is summarized in Table 4.

- The City of Casper uses both groundwater and surface water. Their main source is groundwater (20 wells) with surface water from the North Platte River that supplements the groundwater in the summer. Their annual use in 2005 was 3.6 billion gallons (86 million bbls). The city only has a one-source water piping system - no separate raw and potable water supply lines. They foresee their water supply needs increasing in the next 3 to 5 years and will be looking for additional water. The Pathfinder Reservoir Project is planning on adding 2 1/2 feet of water for domestic water supply that they plan to use as an additional water supply. They have looked into using CBNG produced water from the Rawlins area as a possible source, but did not pursue it because they thought the pipeline costs would be too high and R. O. would have been necessary to treat the water (Hill, 2006). Their water system information is summarized in Table 4.

- The City of Gillette uses groundwater only as a source. The groundwater comes from 26 wells in the Ft. Union, Lance, Fox Hills and Madison formations, and they have five pumping stations. Their average daily water production in 2005 was 4.4 million gpd with a peak use of 13.6 million gpd; their annual use in 2004 was 1.6 billion gallons (40 million bbls). They have a one-source water distributions system - not separate for raw and potable. The community is growing and their long term forecast is to develop more wells (Abelseth, 2006). There was an Aquifer Storage and Retrieval study done in 2002-2003 (WWDC, 2003) that used CBNG water on a small scale, but they are not currently using any CBNG water. It was found that the quantity and quality of the CBNG water was too variable and unpredictable to support even a pilot project. Their water system information is summarized in Table 4.

- The City of Sheridan uses surface water only as a source. Their main supply of water comes from Big Goose Creek, with supplemental water coming from the city–owned Twin Lakes Reservoir (3400 ac-ft) during peak use times. They also have access to water from the Park Reservoir, Dome Lake and Sawmill Lake, all mountain sources of water. They operate two water treatment plants (Sheridan and Big Goose). Their annual water use in 2004 was 1.5 billion gallons (36 million bbls). They have a one-source water distribution system - not separate for raw and potable. They have not looked seriously at using CBNG water as a source. The primary reason was that surface water is subject to a different set of regulations than groundwater and they are considered by EPA as a medium size water treatment facility, which has additional requirements for radon removal. If they added CBNG groundwater as a source, they would need additional treatment facilities to deal with the water than is used for the treatment of surface water. Their water system information is summarized in Table 4.

- The City of Wright uses groundwater as their only source. They currently use groundwater from four wells and are planning on adding another well this winter. Their annual use is around 150 million gallons (3.6 million bbls). They also only have a one-source water distribution system. They at one time were planning on using CBNG produced water out of Hay Creek to irrigate their golf course, but the additional CBNG water from upstream never flowed far enough downstream to reach them. They do not plan on using CBNG water in the future (Kingan, 2006). Their water system information is summarized in Table 4.

Table 4: Summary of Water Sources and 2004 Use Rates for Selected Cities in the PRB

Entity	Total Pop. Served	# of Wells	Surface Source	Treatment Methods [1]	Avg. Daily Use (gpd)	Peak Day Use (gpd)	Total Annual Use (gal)
Buffalo	4,000	1	Clear Creek, Tie Hack Res.	TP	1,252,000	2,055,000	456,980,00
Casper	54,350	20	N. Platte River	DC, F, TP, OT	9,200,000	26,000,000	3,352,000,000
Gillette	25,000	26	None	DC, OT	4,450,000	13,580,000	1,627,720,000
Sheridan	20,000	0	Big Goose Creek, Twin Lakes	TP	4,200,000	10,000,000	1,527,656,000
Wright	1,562	4	None	DC	410,000[2]		149,594,000[2]

[1] Treatment: Disinfection/Chlorination (DC), Filtration (FL), Conventional Water Treatment Plant (TP), Other (OT)
[2] 2005 Data – Kingan, 2006
Source: WWDC, 2004

Potential Benefits and Synergies with Other High Priority Alternatives: Depending on the quality of the water and its end use (raw or potable), a majority of water used by municipalities would require some type of treatment. For the water to be used as potable water by the municipalities, most cities mentioned the use of either a Reverse Osmosis or Ion Exchange treatment system. Water could be treated at small or large facilities at the CBNG fields and transported to the municipality, or water could be transported to the municipality where individual treatment facilities would be constructed.

A pipeline running from the Big George producing area to either of the reservoirs on the North Platte would have the advantage of passing nearby the City of Wright which foresees the need for additional water supply (Kingan, 2006), or other smaller towns that the pipelines may pass near. Access to the Big George pipeline may allow them to take some of this water either in the raw form for various uses such as irrigation, or for drinking water after treatment. The reservoirs that receive the CBNG water are also used by municipalities that use the water as their source and can supply additional water supply needs. Other municipalities such as Buffalo, Sheridan, and Gillette have considered using water from Lake De Smet to meet their future water supply needs.

Political and Public Perception Barriers and the Potential for NGO Lawsuits: Similar perceptions and barriers to those found with the water treatment and discharge to reservoir alternatives would be possible for this alternative. These could include the additional infrastructure for treatment plants, pipeline concerns, waste product disposal, and long-range interbasin transfer of Big George water. Also integral to this alternative is the public's view of CBNG produced water as a resource and not a waste product. The feasibility of beneficially using produced water for municipal uses requires a change in mindset that takes into account operational needs and a stringent regulatory framework put in-place to protect public water supplies and the individuals using and consuming water. Using produced water may require a more rigorous sampling and analysis program than many producers are used to. Close coordination with the various stakeholders will also be critical to the success of this water management alternative.

Regulatory Feasibility and Barriers: Similar permitting barriers could be raised to this alternative as to the water treatment alternative and those involving long-range, inter basin transfer of Big George water. New water treatment plants will need an appropriate construction permit, WPDES permit, and WOGCC pit permit.

In Wyoming, the EPA Region 8 is responsible for overseeing the public water supply program. EPA Region 8 is responsible for compliance, monitoring, tracking, and enforcing the Safe Drinking Water Act (SDWA) for the state's public water systems. The WDEQ oversees the public water system operator certification program, plan and specifications review and approval program, State Revolving Fund program, and the source water protection program. There is an extensive regulatory burden placed upon public water suppliers because they can have a direct bearing on the health of thousands of people. The regulations would be the same whether the water supply would be from groundwater wells or CBNG producing facilities. The regulatory burden, however, would be upon the municipality, not the CBNG operator.

Technical Feasibility and Compatibility of Big George Produced Water: Depending upon the beneficial use (potable or non-potable), the produced water will most likely need subsequent treatment. If the water is to be used by the municipality for irrigation, the irrigation practices would need to be managed in a manner to not harm vegetation or soils due to the higher SAR and sodium content of CBNG produced water.

Big George water quality is low for CBNG water and exceeds the national secondary standard for TDS (500 mg/L). From the data presented in Figure 1, the average TDS of Big George water is about 2140 mg/L, with none of the values being below 500 mg/L. From additional studies performed in the Gillette area in the Big George (WWDC, 2003), iron and manganese also exceeded regulatory standards for drinking water. Big George water would need to be treated for it to be suitable for drinking water. Technologies and costs involved in the various treatment techniques are detailed in the treatment and discharge option above. Reverse Osmosis and Ion Exchange would most likely be the most feasible treatment options.

The non-consumptive use of CBNG produced water would be constrained by additional infrastructure required (dual supply water system) for such an application. If CBNG produced water were to be supplied for non-potable water uses to a municipality, additional piping and control mechanisms would be required. Depending on the extent to which this application would be used throughout the area and the extent to which a continued supply could be provided for these applications, the long term cost effectiveness of reduced potable water use may justify this application. Currently, Buffalo was the only city contacted in the PRB that had a dual supply water system, with the raw water system coming from a well and used only for irrigation.

The largest technical barrier to using CBNG produced water for municipal applications would also be the inconsistent volume and short duration of the supply of produced water. CBNG wells have a limited well life and produce at a declining rate over time; a municipality may not want to make a significant investment if the volume to be supplied is not significant or is only a short term supply. Existing CBNG development around Gillette had been supplying CBNG produced water to the city municipal supply through an ASR pilot program. However, since the project was initiated the CBNG development in the area was unable to provide sufficient quantities of high quality water to meet the city's needs (WWDC, 2003). Every municipality contacted expressed the concern of inconsistent quantity and/or quality and long term availability of the CBNG water, and that was one, if not the main reason they were not interested in using produce water for a drinking water source (Allgood, 2006; Cole, 2006; Kingan, 2006; Hill, 2006; and Abelseth, 2006).

Economic Feasibility Including Transportation Costs and Treatment Costs if Required: Depending on the end use of the produced water (potable or non-potable), the costs will vary. If the water is to be used for non-potable uses only, transportation will most likely be the only cost, will be similar to that discussed earlier, and will vary by location. If the water is used for irrigation purposes, there will be some minimal treatment costs for amendment applications/treatment. For water being used for potable water, treatment costs would be similar to those given in the Treatment Alternative in Table 2 and the accompanying discussion. As stated above, Reverse Osmosis or Ion Exchange would be the most feasible options; additional costs would include waste disposal as discussed earlier. Transportation will need to be by way of truck for small volumes or pipelines for large volumes. Pipeline costs will vary by the size of the line and its length as well as other factors such as terrain to be crossed and net change in elevation. Costs for installation of a dual supply water system are not included in this analysis since it would most likely be too cost prohibitive to install.

Legislative Implications of the Alternative with Emphasis on Opportunities for Relief: As discussed under the other alternatives involving long-range interbasin transfer of water, enabling legislation may be required to allow transfer of produced water between watersheds for designated beneficial uses. Legislative incentives could involve guaranteed loans for the pipeline system or assistance for condemnation of the right-of-way. Other legislative implications will be similar to those included in the Treatment Alternative that involve waste disposal.

Timing Issues Including Sensitivity Analysis: Timing issues will be similar to that of the Treatment Alternative related to treatment systems and pipelines. Installation of the pipeline from CBNG projects to the municipal water plants will be of varying length but its installation will be routine. The municipal water department will likely require additional time to plan for storage and treatment prior to usage. Convincing municipalities to accept beneficial use of the water based on consistent and long term supply of the water, and for outlaying funds for required infrastructure may be a significant hurdle.

Alternative 4: Use in Power Plants as Cooling Medium

Description: Several large electrical power plants exist in the vicinity of the PRB. Most are close to the coal mines in the basin. The largest plants in the area, the Laramie River Station, located near the city of Wheatland and the Dave Johnston power plant east of Casper use a wet cooling cycle that requires large volumes of water during every day of operation. The Laramie River Station power plant uses water from the drought-depleted Grayrocks Reservoir and is running low on water reserves. Laramie Station currently must look elsewhere for cooling resources. The Dave Johnston plant uses water from the North Platte River, which is facing water supply difficulties as discussed above. CBNG produced water may be a valuable resource for power plant operators in the PRB.

Potential Benefits of Alternative with Emphasis on Synergies with Other Alternatives: Water supplied to power plants in northeastern Wyoming will provide added options for the power plant operators although not for as long a time as the plant is designed to operate. With the location of most of the power plants being close to coal mines, it would make sense to suggest that any Big George water transported near the power plants could also be made available to local coal mines for dust control. In addition, pipelines from Big George production to power plants could also pass by county roads needing dust application and may pass public reservoirs that could benefit with additional fill-up. Each one of these beneficial uses of Big George water may have its own water quality requirements; those with stringent quality requirements would likely need to have a dedicated water treatment facility in the vicinity of the plant or reservoir.

Political and Public Relations Barriers and Potential for NGO Lawsuits: Similar objections could be raised to this alternative as to others involving long-range, interbasin transfer of Big George water.

Regulatory Feasibility and Barriers: Similar permitting barriers could be raised to this alternative as to others involving long-range, interbasin transfer of Big George water.

Technical Feasibility Including Compatibility of Big George Water to Each Alternative: Individual power plants will have their own design criteria for cooling water. The design specifications will control the range of water quality needed by the plant. Two of the larger power plants in the basin – Laramie River Station and Dave Johnson – both use raw river water from the North Platte River. The former uses approximately 500,000 bbls/day while the latter uses between 150,000 and 200,000 bbls/day (Dugan, 2006). Big George water may be compatible with plant quality demands. Cooling water is discharged back to the North Platte River after running through the plant and the return water will need to be of similar quality to the water as described under Alternative 2 above. Quality of the return water is the limiting factor because Big George water could not be discharged to the river in its raw form after use in the cooling cycle without degrading the North Platte River. Water treatment would be required before the water could be discharged or the water could be treated prior to use in the power plants.

Economic Feasibility Including Transportation Costs and Treatment Costs if Required: Transportation costs will vary by location as discussed above. If the pipeline system is long, costs will be higher. If the pipeline crosses a ridgeline or crosses a deep drainage, costs will be higher. The two power plants most in need of water – Dave Johnson and Laramie River Station – are more than 100 miles from the concentration of Big George production. Treatment costs will be determined by water quality requirements at the individual plants and, in particular, determined by the water quality of the receiving stream. Therefore, the estimated costs of this alternative are seen to be similar to the estimated costs for reservoir discharge (Alternative 2).

Legislative Implications of the Alternative and Opportunities for Relief: As discussed under the other alternatives involving long-range interbasin transfer of water, enabling legislation may be required to allow transfer of produced water between watersheds for designated beneficial uses. Legislative incentives could involve guaranteed loans for the pipeline system or assistance for condemnation of the right-of-way.

Timing Issues Including Sensitivity Analysis: The only area of uncertainty with using Big George water for cooling at area power plants is construction of the long distance pipelines and construction of any required water treatment facilities.

Alternative 5: Use in Coal Mines to Control Dust

Description: Wyoming is the largest coal-producing state in the nation. PRB mines are the largest in Wyoming and as such are major sources of air quality impacts in the region. Dust generated in coal mines has increased in the past three years to the point of exceeding air quality permits (Murphree, 2005). Dust from mines contributes to local problems with PM_{10} (particulate matter with an equivalent aerodynamic diameter of 10 microns or less) pollution in the PRB. Within the past five years, PM_{10} standards have been exceeded in the PRB, especially to the east of the coal mine belt (D. Olson, 2006). The DEQ maintains between 35 and 40 air quality monitors around the PRB that automatically notify the WDEQ if standards are exceeded. When exceedances occur, the EPA is notified and a notice of exceedance is sent to the coal mine operator.

When exceedances began to occur in 2001, the WDEQ assembled a consortium of coal mine operators, CBNG operators, and county commissioners to devise plans to mitigate the air quality problems (D. Olson, 2006). The direct result of the planning efforts was the increased level of road watering by the mines using mine water and some CBNG water. At this same time, the WDEQ agreed to assign primary permitting duties for road spreading of oil and gas produced water to the WOGCC; this has greatly simplified the process (Searle, 2005). Although some exceedances still occur, the problems are fewer and watering was the answer.

Dust is a public relations issue in the PRB contributing to increased levels of citizen complaints to county officials and WDEQ staff (D. Olson, 2006). The dust issue increasingly finds itself in the news (Bleizeffer, 2006). Being an arid, rural region with few paved roads, the increases in industrial and residential traffic generate dust problems on a local or regional scale. No areas in Wyoming are in danger of non-attainment status in terms of air quality (D. Olson, 2006). But some locations such as those downwind of large coal mines and adjacent to some heavily traveled clinker roads can have dust problems. Big George produced waters could be a partial solution to this problem.

At the present time the Wyoming State Office of the BLM is in the process of completing a review of the cumulative impacts of coal mining in the PRB over the next 20 years. A major aspect of this review is air quality, in particular, PM_{10} dust. If dust from haul roads cannot be controlled at existing PRB coal mines, coal mining and road building may be severely restricted on federal lands throughout the PRB. It is most important that the watering regime developed in the 2001-2002 timeframe be continued.

Large coal mines have a considerable inventory of haul roads and with increased production they see a great deal of truck traffic on those roads. During dry periods, the traffic can result in dust unless roads are watered. For example, the North Antelope / Rochelle Complex (NA/RC), the world's largest coal mine, is located south of Gillette. The NA/RC uses water for a variety of uses including haul road dust suppression, facilities wash-down, and potable water (Murphree, 2005). Facility wash-down includes the frequent washing of all crusher and transfer facilities as well as the periodic washing of equipment and vehicles. All potable water and much of the wash-down water is provided by deep water supply wells. However, only a portion of the haul road water budget is provided by wells. The mine uses three water supply wells placed in the Fort Union Formation. These wells are approximately 2,000 feet deep and produce approximately 200 gpm of high quality water (TDS ~250 mg/l). A single 5,300-foot deep well drilled into the Fox Hills Formation provides approximately 350 gpm of lesser quality water (TDS ~750 mg/l).

Water recaptured from the mine's primary downstream sedimentation ponds and from a shallow clinker aquifer adjacent to the facility area and recycled back through the water supply pond has significantly reduced the use of groundwater. The sedimentation ponds have been used to store CBNG water in the mines.

The maximum daily use for haul road dust suppression in the summer months is approximately 85,000 bpd per mine, while the minimum daily use in the winter is approximately 2,500 bpd. Prior to 1996, almost all of the water needs were provided by groundwater pumped to tanks or reservoirs while stormwater runoff water was discharged from the mine site. However, as the mine began to expand and it increased production, water use at the mine began to exceed the capacity of the wells at the mine. In order to provide a secondary source of water, sediment ponds were converted to holding ponds to supply watering trucks. Today, most haul road dust suppression water is provided from water supply ponds placed on the mine backfill. Water use at the mine is expected to increase over the next few years due to the lengthening of haul roads and continuing efforts to meet strict dust control standards (Murphree, 2005).

CBNG water had been used in the mine from the development adjacent to the mine workings but as production declined, most or all of the water was used by the operator and local ranchers. This water was high quality, averaging 435 mg/L TDS and an SAR of approximately 6 (Murphree, 2005). There no longer are producing CBNG wells in the area.

Potential Benefits and Synergies with Other High Priority Alternatives: Road application of CBNG produced water will reduce dust levels. Reduction of PM_{10} levels in the PRB will allow further industrialization in the area without further impact to air quality. Transporting CBNG water from the Big George area near the axis of the basin approximately 15 miles to the west of the coal mine belt will help the coal mine operators cope with decreasing surface water supplies. CBNG water could help maintain road application of water to control dust.

Road traffic is directly tied to mine activity and coal production. At the present time coal demand, production, and cost are at all-time highs (EIA, 2006). This activity correlates with a high level of traffic on area roads and a demand for water for dust control. While coal mining activity is likely to continue past the time of peak Big George water production, the water will be useful. Big George water is appropriate for dust control since there are no water quality limits for road application. Some coal mine operators prefer higher quality water while others prefer low quality water. Water treatment may not be necessary. Road application may not be appropriate near agricultural crops or other locations vulnerable to salinity increases. Within coal mine boundaries, however, road application should be appropriate.

Pipeline transportation of Big George water may be complementary to other beneficial uses such as cooling medium in area power plants and dust control on county roads. Power plants in the PRB are located near coal mines; a common pipeline could deliver CBNG water to be used by power plants for cooling and by mines for dust control. Some power plants may be able to use raw Big George water while others will need to treat the water to their own specifications. Power plants and coal mines will need to be able to store water near their facilities as produced water supply may not be consistent and may not correspond to times of peak use.

Counties such as Campbell and Johnson could also use raw water from the pipeline for road spreading if supplied with several secure taps. County road maintenance staff could fill trucks at the nearest tap and transport the water to where it was needed.

Secondary oil recovery projects such as water floods can be beneficial users of large volumes of CBNG produced water. Water flood operations are engineered to recover crude oil from deep reservoirs that would not be recovered by initial "primary" production. The use of Big George water in such operations is indeed a beneficial use since the operator is recovering unproduceable oil reserves in the process. Water flooding operations are described more fully in Section 3 below. Secondary recovery water flood projects along the pipeline may require large volumes of water, especially during early phases of their operations before fill-up of the reservoir takes place. Secondary recovery operations could happen at any time of the year unlike dust control and cooling which would be concentrated in the summer.

Political and Public Relations Barriers and Potential for NGO Lawsuits: Dust is a problem throughout the PRB that is in the news (Bleizeffer, 2006). It would be a good argument supporting the use of Big George water that the water will reduce dust within the basin and especially reduce dust near the mines. The perception would have to be that reduction of coal mine dust would allow many kinds of further development of the PRB.

On the other hand, farmers and ranchers in the center of the basin may look upon the proposed high-volume transfer of the water as a waste of a valuable agricultural resource. This is a reiteration of the conflict between industrial and agricultural uses of resources. Coal mine interests will need to point out that industrial development in the basin will provide a wide variety of gainful employment in the basin. Most of the new industrial activity will be similar to historical industry in the basin; citizens of Wyoming are accustomed to this development.

Regulatory Feasibility and Barriers: The WOGCC permits this activity by way of Form 20. While this process is quite simple, if federal minerals are involved as either the source of the produced water or is the surface containing the haul road, the activity is subject to the NEPA process. In the case of road application of produced salt water, NEPA documentation may need to be submitted (Beels, 2006). Depending upon the level of NEPA documentation required by the federal authorizing official, public involvement may also be mandated. In the case of application of produced water to haul roads, potential impacts to the environment and may require modeling of the dissolved salts. Among the possible impacts, the models may need to analyze the following:

- Salinity and sodium impacts to plants and animals near the roadsides.
- Salinity buildup in soils near roads.
- Sodium impacts to soil, reducing surface permeability and promoting soil erosion.
- Heavy metal impacts from trace elements in the specific brine.
- Corrosion impacts to concrete and metal bridges and structures.
- Pond stratification caused by brine impact.

Technical Feasibility Including Compatibility of Big George Water: Compatibility of Big George water will need to be demonstrated by way of the EA discussed above. If a large coal mine averages 50,000 bpd of Big George (approximately 2,400 mg/L TDS) water spread on 15 miles of road, this is approximately one million pounds of salt per mile per year. But each of these parameters will change at each mine. Detailed loading models will need to be performed for specific coal mines to determine the appropriateness of applying large volumes of Big George water.

Economic Feasibility Including Transportation Costs and Treatment Costs: The economics of providing water for dust control is dominated by the capital costs of the pipeline system and operating costs of the system. During five years' time, this pipeline would have the capacity to transfer approximately 365 million bbls of Big George water. If the pipeline system were 20 miles of total length, using the assumptions from Alternative 2, costs would be approximately $17 million or an average of $0.046 per bbl of water transferred over five years. Operations and maintenance may add $0.05/bbl to the cost. The total of approximately $0.10/bbl will depend on the specifics of pipeline location.

Transportation will need to be by way of pipeline as discharge to streams does not appear possible for several reasons. Few streams travel from the Big George producing area toward the coal mines east of Gillette. Midway between the two areas is the divide between the Powder River and the Belle Fourche watersheds. Water would need to be pipelined over this divide. Streams such as Caballo Creek that flows east are intermittent and would be perennialized by the discharge of large amounts of Big George water. It would very likely be impossible to get a WPDES permit to discharge untreated Big George water through the WDEQ.

Legislative Implications of the Alternative and Opportunities for Relief: This alternative has the promise to mitigate dust problems in the PRB while managing water from the Big George. Legislative incentives could involve guaranteed loans for the pipeline system or assistance for condemnation of the right-of-way. State government may be able to facilitate and streamline the EA process needed to allow spreading of the produced water on haul roads.

Timing Issues Including Sensitivity Analysis: If modeling suggests that environmental impacts from use of raw produced water would be excessive, the Big George water may need to be at least partially treated prior to road spreading. The added complication of citing, designing, and permitting appropriate treatment facilities may affect the implementation of this management alternative.

Section 3: Feasibility of CBNG Low Priority Water Management Alternatives

In addition to the high priority management alternatives discussed above, there are two low priority alternatives that have a low threshold of implementation and can be easily permitted but appear to lack the ability to use large volumes of Big George produced water. Class II deep disposal wells and Class II water flood injection wells both have been utilized in the PRB and both are potentially compatible with handling Big George water. Both alternatives, however, are limited in their application by geographic location and geological factors.

Both alternatives involve injection of produced water well below producing coal seams in the PRB. Deep disposal wells use injection as a way of disposing of waste water; once the water is injected it mixes in the deep reservoir with strong subsurface brines and is no longer usable. Water flood injection is a beneficial use of the injected water that increases the recovery of crude oil from some reservoirs. Water flood operations are engineered to recover crude oil from deep reservoirs that would not be recovered by initial "primary" production. The use of Big George water in such operations is indeed a beneficial use since the operator is recovering unproduceable oil reserves in the process. Water flooding involves pumping water into the crude oil reservoir to increase the pressure in the reservoir and to enhance the flow of fluid in the reservoir toward the producing wells. In the initial stage of the water flood, large volumes of water are required before the reservoir fills and the increased pressure is seen at the producing wells. Up until that point, the oil wells may be producing little water from the flood. It is the initial stage of the flood that will require the largest volumes of water.

Potential Benefits of the Alternatives and Potential Synergies with High Priority Alternatives: Both the disposal and water flood alternatives remove Big George water from the environment. There are virtually no potential impacts to the environment from either of these alternatives, excepting inadvertent releases and leaks at the surface. Both of these low priority alternatives have the potential to be compatible to the high priority alternatives discussed above. Both alternatives have the potential to manage up to 50,000 to 100,000 bpd of water at a large field or disposal facility.

The location of oil fields is largely between the Big George producing area and the coal mines and coal power plants to the east. Water flood operators could arrange to withdraw some of the Big George stream for localized beneficial use. Deep disposal wells can be drilled and installed at many locations around the basin and some of these potential locations may be along the interbasin transfer pipelines.

Political and Public Relations Barriers and Potential for NGO Lawsuits: Replenishing reservoirs is a high order of beneficial use that should be perceived by the public as suitable and applicable. The higher order of beneficial use may be seen by the public as overcoming their objections to removing deep water resources from their watershed. While replenishing reservoirs can indeed represent the removal of water from, for instance, the Powder River watershed to the N. Platte River watershed, this water in the Big George seam aquifer is so deep that it is unlikely to be tapped by ranchers and farmers in water supply wells. At these depths, the CBNG water does not seem to constitute a valuable water resource. The comparison of removing a deep, marginal water resource and making it replenish a diminishing reservoir may demonstrate that this alternative of produced water management is indeed a higher use of the resource. It also needs to be emphasized that the produced water that will be piped into the reservoirs under this alternative is the remainder after the local land owner is given his share of water for local use either for managed irrigation or livestock; the local rancher will not be denied this resource.

Regulatory Feasibility and Barriers: Similar permitting barriers could be raised to this alternative as to others involving long-range, interbasin transfer of Big George water.

Technical Feasibility Including Compatibility of Big George Water to Alternative Use: Big George water may be compatible with some water flood applications in its raw form but many crude oil reservoirs will require some treatment of Big George water (Cline, 2006). The treatment most often mentioned involves removal of bicarbonate ions from the water to avoid scaling within the borehole and within the producing formation near the injection boreholes (Sealey, 2006). In addition, Big George water will need to be filtered and treated for any other scaling constituents; nevertheless, CBNG water in general and Big George water in particular is thought to be attractive for injection into water floods, especially in the early fill-up stage of the operation (Sealey, 2006).

Big George produced water should likewise be compatible with most disposal injection projects. Few formations in the PRB, however, have the potential to dispose of large volumes of water except the Madison (Likwartz, 2005). The thick, occasionally fractured carbonates of the Madison Formation have the ability to accept large volumes of injected water (Cline, 2006) but this is not true across the entire basin. The ability to predict fracture density will help operators locate deep disposal wells targeting the Madison.

Economic Feasibility Including Transportation Costs and Treatment Costs if Required: Transportation costs will vary by location as discussed above. Treatment costs will be determined by water quality requirements at the individual water flood projects.

Legislative Implications of the Alternative and Opportunities for Relief: As discussed under the other alternatives involving long-range interbasin transfer of water, enabling legislation may be required to allow transfer of produced water between watersheds for designated beneficial uses such as enhanced recovery of oil using water flood technology.

Timing Issues Including Sensitivity Analysis: The only area of uncertainty with using Big George water for water floods is construction of the long distance pipelines and construction of any required water treatment facilities.

Section 4: Summary and Conclusions

Phase II research coupled with conversations with the contributors make it clear that this is the best time to change the regulatory philosophy of the State of Wyoming. CBNG produced water is best seen not as a waste to be closely regulated and quickly disposed of, but a valuable resource whose possible uses can help the citizens of the state. Our focus should not be on the potential local harm that may be done by accidental releases of this water. Our focus must instead be on getting this valuable commodity to those citizens and industries in our state that can best use it. The Governor's Planning Office has set the sights of this report on these vital questions:

- What are the most important, most feasible uses appropriate for this produced water?

  and,

- How can the produced water be transported to those high priority uses?

Of the 13 water management options reviewed in Phase I, the contributors identified five high priority, feasible options. These management options – power plant cooling water, dust control, discharge to public reservoirs, public drinking water supply, and treatment and discharge – bear directly on the state's water needs that have been exacerbated by the drought conditions since 1998:

- Scarce supply of agricultural water for livestock and crop irrigation. Cattle ranchers have utilized CBNG water since its inception and irrigation projects have been successful in several parts of the basin using raw CBNG water.
- Lack of water resources for dust control on coal mine haul roads and county roads has caused an air quality problem in the basin.
- Local lack of water threatens to curtail power plant operations in the PRB.
- Lack of drinking water resources in the basin may not permit continued growth of the basin's cities.

The five high priority management alternatives can be utilized with a high-volume Powder River Basin pipeline system to transport water from the Big George and similar CBNG fields near the center of the basin to end users on the edges of the basin. The system can be designed to connect the major water production to the coal mines, power plants, public reservoirs, and major towns and cities. The system will be owned by an entity separate from the CBNG producers and end users, whether a public agency or a consortium of private companies. The system may have a number of outlets each controlled by different end users such as the following:

- Coal mines need produced water for dust control on haul roads, especially during dry periods in the summer and fall.

- Counties need produced water for dust control on county roads, especially during dry periods in the summer and fall.
- New crude oil fields need raw produced water for secondary recovery (waterflood) operations during all times of the year.
- Treatment facilities can supply high quality water to public systems during peak times in the summer.
- Treatment facilities can supply variable quality, appropriate water to public reservoirs during periods of low natural flow and during irrigation season.
- Treatment facilities can supply appropriate water to power plants during the summer when their need is greatest.

These end users could make use of water volumes in excess of 500,000 bpd of CBNG water. These beneficial uses are appropriate for Big George water in terms of water quality and timing of the resource. These five uses can be facilitated by coordinated agency emphasis and legislative advocacy. Putting this water supply system in place will help the coal industry, will help air quality in the PRB, will give the power industry breathing room to secure cooling capacity, and will replenish reservoirs in the area. And use of the water supply system will reassure the CBNG industry that large volumes of produced water can be managed safely and economically, enabling this industry to continue to expand its development of this very valuable resource. The use of CBNG water in a coordinated system can benefit businesses and citizens around the state of Wyoming.

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Appendix A - Big George Water Quality

Big George Water Quality (Source: USGS)

Township	Range	Section	Elec. Cond	SAR
48	77	36	3460	28.6
46	73	7	1312	10.1
43	73	32	1475	9.1
43	74	28	1351	8.4
48	76	15	2060	17.1
49	76	19	2340	22.7
47	77	36	2820	22.7
43	73	4	980	9.8
43	74	1	1140	7.9
48	75	36	1507	15.2
42	75	36	1104	7.4
48	77	16	3990	26.4
48	77	16	4050	27.0
48	77	16	4080	26.9
48	77	22	4250	26.9
48	77	15	4230	26.4
48	77	10	4210	26.8
48	77	21	4300	27.1
48	77	15	4270	27.9
48	77	9	4150	28.2
42	77	16	1920	12.0
42	77	8	1748	9.1
50	75	21	2170	17.1
46	74	5	1763	10.5
46	75	13	1939	12.3
48	77	16	3840	23.5
48	77	15	4040	24.5
48	77	9	3930	23.7
47	77	29	3660	21.8
44	74	16	1148	10.5
44	74	33	1293	10.1
47	78	5	2860	22.3
47	78	16	3120	26.0
50	77	29	3900	35.9
50	78	25	3700	45.4
50	77	6	3950	39.2
51	78	36	4400	44.7
48	77	16	3750	26.5
48	77	15	3950	28.0
48	77	9	3710	27.5
43	74	24	1088	8.5
46	74	26	1365	11.0
49	76	2	2780	25.9

Big George Water Quality (Source: USGS)

Township	Range	Section	Elec. Cond	SAR
43	75	21	1821	8.9
45	74	36	1367	10.0
42	75	1	1387	7.9
47	77	23	4420	30.8
43	75	3	1590	9.2
43	77	11	2910	21.0
42	74	15	1136	7.3
49	75	3	2970	19.7
Mean			**2758.9**	**20.3**

Appendix B – EPA Letter for Brine Disposal

MC Engr —
reverse osmosis
8/5

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 8
999 18TH STREET - SUITE 300
DENVER, CO 80202-2466
Phone 800-227-8917
http://www.epa.gov/region08

Ref: 8P-W-GW

Mr. Bill Courtney
EMIT Water Discharge
Technology
P. O. BOX 6785
Sheridan, WY 82801

RE: Regulatory Status of Acidic Brine from Regeneration of a Higgins Loop Continuous Ion Exchange Water Treatment System

Dear Mr. Courtney:

This letter is in response to your discussions with Paul Osborne and our review of the technical material faxed to Mr Osborne on July 27, 2004. You requested an opinion from EPA as to whether the regeneration brine from the Higgins Loop Continuous Ion Exchange Water Treatment System was exempt from Subtitle C of RCRA under the E&P exclusion. Our review of this issue was coordinated with RCRA program staff in Headquarters. We have also coordinated our response with our Regional Program and with the Wyoming Department of Environmental Quality, Water Quality Division who has Primary enforcement authority for EPA's Program for the regulation of underground injection.

Based on the information that you supplied, EPA has concluded that the waste in question, the brine discharged from the Higgins Loop, is waste from a treatment process that is not intrinsic to exploration and production operations. Therefore, the waste is not an exempt E&P waste. Additionally, the regeneration brine does not meet the regulatory definition of a Class II waste under 40 CFR 144.6(b)(1). Because the waste has a pH of less than 2, it exhibits the characteristic of corrosivity under 40 CFR 261.22 and would be defined as a hazardous waste. As such this waste would have to go to a hazardous waste disposal facility unless the brine is treated on-site to raise the pH to an acceptable level (above a pH of 2). If treatment was performed, the fluid could be injected into a Class I non-hazardous disposal well (see 40 CFR 144.6(a)(2)).

On a related topic, it is our understanding the Wyoming Oil and Gas Commission Order #345-2003 specifically restricts removal of waste generated at the lease location of your test facility. This issue would have to be addressed by requesting and obtaining a modification of the order before you can haul any waste, either solid or liquid, off-site for disposal.

We hope that this adequately addresses your question. If you have any questions or concerns, please call Paul S. Osborne, at (303) 312-6125.

Sincerely,

Stephen S. Tuber
Assistant Regional Administrator
Office of Partnerships and Regulatory Assistance

cc: John Wagner, WDEQ
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Kevin Frederick, WDEQ
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